

The effect of production system and age on levels of iron, taurine, carnosine, coenzyme Q₁₀, and creatine in beef muscles and liver

R.W. Purchas^{a,*}, J.R. Busboom^b

^a *Institute of Food, Nutrition and Human Health, Massey University, Private Bag 11 222, Palmerston North, New Zealand*

^b *Department of Animal Sciences, Washington State University, Box 646310, Pullman, WA 99164-6310, USA*

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Abstract

Samples of longissimus (LL) and triceps brachii (TB) muscles from Angus-cross heifers finished either on a high-concentrate ration in Washington, USA, (US cattle, $n = 15$) or on pasture in New Zealand (NZ cattle, $n = 16$) were assessed for composition characteristics. Half of the NZ cattle were of a similar age to the US cattle (NZAge) and half were of a similar weight (NZWt). Iron concentration was higher in TB (20.9 vs. 17.5 $\mu\text{g g}^{-1}$; $P < 0.001$) and was higher for the NZWt group than the NZAge group or the US cattle. The proportion of iron as haem iron was highest for the NZWt group (87.3%; $P < 0.01$), but the proportion as soluble haem iron was highest for the US cattle. For a sub-group of 10 pasture-finished cattle, iron levels in cheek muscle were higher than for LL or TB, and liver levels were 66% higher than cheek muscle. The proportion of haem iron, however, was lowest in liver (55.3%) and was lower in cheek muscle (78.4%) than LL or TB. Relative to LL, TB had higher levels of taurine and coenzyme Q₁₀, but lower levels of carnosine, creatine and creatinine, as expected for a muscle with a more aerobic metabolism. These differences were magnified for the even more aerobic cheek muscle. Differences between the two NZ groups were small, but muscles from the US cattle contained less taurine, carnosine, coenzyme Q₁₀, and creatinine. Reasons for these differences in various meat components for similar cattle from different production systems are not clear.

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1. Introduction

A considerable amount of information is available on factors affecting the composition of beef from different production systems within countries, but comparisons have rarely been made between beef from production systems of different countries. This is understandable because, if differences are shown, it is not possible to clearly separate out the effects of the systems per se from differences in the genetic background of the animals or other uncontrollable differences between the countries.

Furthermore, there will usually be many variables within any broadly defined production system, such as feedlot finishing or pasture finishing, that may influence beef composition. With approximately 12% of world beef production being traded internationally (MWIL-ES, 2003), however, it is important that the possibility that significant differences in beef composition between different sources be investigated, but with the understanding that, should significant differences be shown to exist, they will need to be assessed further in controlled trials.

Beef is a significant source of iron in the diet of many people (Uzel & Conrad, 1998) and the proportion of the iron present in the haem form and as part of water-soluble compounds is important because of possible

* Corresponding author. Tel.: +64 6 350 4336x2536; fax: +64 6 350 5657.

E-mail address: r.purchas@massey.ac.nz (R.W. Purchas).

differences in the bioavailability of iron in the different forms (Boech et al., 2003). Interest in levels of taurine, carnosine, coenzyme Q₁₀, and creatine in meat arises from possible bioactive properties of these compounds as discussed by Purchas, Rutherford, Pearce, Vather, and Wilkinson (2004). Taurine has a multitude of physiological functions including some associated with eye health (Huxtable, 1992) and heart disease (Militante & Lombardini, 2001), carnosine has a buffering role in muscle, and along with coenzyme Q₁₀, has antioxidant properties (Decker & Mei, 1996). The extent to which supplemental coenzyme Q₁₀ has health benefits has been investigated widely (Hargreaves, 2003). Creatine is important to muscle energy metabolism and has been shown to be useful as an ergogenic aid in some studies (Juhn, 2003).

The results reported herein are for beef from Angus-cross heifers finished either on a high-concentrate feedlot ration in Washington State in the USA or on pasture in New Zealand. Composition characteristics measured in two muscles included the level of iron and the proportion of iron in several forms, together with levels of taurine, carnosine, coenzyme Q₁₀ and creatine. For a sub-sample of the New Zealand cattle only, levels in cheek muscle and liver were also measured.

2. Materials and methods

2.1. Animals and samples

The 31 Angus-cross heifers used included 15 from Washington State in the USA (US cattle) and 16 from New Zealand (NZ cattle). The US cattle, which were Angus-sired out of Hereford and Angus × Hereford cross cows, were placed in a feedlot at 12–13 months of age following a period of backgrounding. In the feedlot they were adjusted over a period of 4 weeks to a high-concentrate finishing diet (Table 1) that they received for 98 days prior to slaughter at 16–17 months. A noteworthy feature of this diet was the relatively high content of potato products.

For the NZ cattle, details of their breed makeup apart from the Angus component, were not known with cer-

tainty, but included a Hereford or Simmental background as indicated by white faces. The heifers, which were raised on pastures of primarily perennial ryegrass and white clover from birth, comprised two separate lots. One lot of eight (NZAge) were of a similar age to the US cattle but lighter, while the second lot of eight (NZWt) were of a similar weight to the US cattle but older.

Slaughter and dressing procedures followed normal commercial procedures in the relevant country for each group. On the day following slaughter all carcasses were evaluated for marbling, maturity, and USDA quality grade by the same person (JRB). Also, on the day following slaughter, samples from the cranial end of *M. longissimus lumborum* (700–900 g) (LL) and from the central distal part of *M. triceps brachii (longum)* (200–300 g) (TB) were taken. For the NZ cattle only, samples (100–200 g) were also taken from the liver and cheek muscle (primarily *M. masseter*) within 1 h post-mortem. All samples were frozen at –20 °C within 36 h post-mortem. The ultimate pH of the LL and TB samples were measured on freshly cut surfaces of thawed muscle with a spear combination electrode (Sensorex, USA).

2.2. Analytical measurements

The proportions of iron as haem iron and non-haem iron in the water soluble and water insoluble fractions were assessed as described by Purchas, Simcock, Knight, and Wilkinson (2003). Briefly, haem iron was assessed using the colorimetric method of Hornsey (1956), and non-haem iron was assayed colorimetrically using the ferrozine method after removal of haem iron by trichloroacetic acid precipitation. Total iron was calculated as the sum of the soluble and insoluble iron.

Taurine, carnosine, coenzyme Q₁₀, creatine and creatinine were assayed in freeze-dried samples of the muscle and liver as described by Purchas et al. (2004). Briefly, taurine and carnosine were quantified using an HPLC system after a buffer extract (67 mM sodium citrate buffer, pH 2.2) had been passed through an ultrafilter with a 5000 MW cutoff. Coenzyme Q₁₀ was measured in hexane extracts by HPLC. Creatine and creatinine were assayed spectrophotometrically using enzyme-based systems in an auto-analyser (Purchas et al., 2004).

2.3. Statistical analysis

For samples from all 31 animals, a block design was used within the GLM Procedure of SAS (SAS Inst. Inc., Cary, NC), with individual animals as the blocks and the two muscles as samples within each block. Thus, the group effect was tested against the animal-within-group term, and the effects of animal, muscle, and group-by-muscle

Table 1
The composition of the diet fed to the US cattle for a period of 98 days prior to slaughter expressed as a percentage of dry matter (DM)

Ingredient	% DM
Barley	26.5
Corn	25.4
Potato slurry	18.5
French fries	8.5
Wheat midds	8.0
Alfalfa hay	6.0
Supplement	3.8
Tallow	3.3

interaction were tested against the overall error term. Multiple comparisons between groups were tested using the least-significant-difference method. For the 10 pasture-finished animals with data for liver and cheek muscle as well as the other two muscles, a similar model was used, except there were only two groups and four tissues (three muscles and liver).

3. Results and discussion

3.1. Iron levels

Results in Table 2 indicate that the ages of the US cattle and the NZAge group were similar at 16–17 months, and that the NZWt group was about 9 months older at 27–28 months. Teeth eruption patterns at slaughter for the NZ cattle were consistent with this age difference (Andrews, 1975), with no erupted permanent incisor teeth for the NZAge group but mainly 2 erupted permanent incisor teeth for the NZWt group (1 with none, 1 with 1.5, and 6 with 2). The mean carcass weight for the US cattle was about 60 kg greater than for the NZAge group as expected, but was also significantly greater than for the NZWt group (Table 2). Adjusted fat depths at the 12th rib and levels of marbling were significantly higher for the US cattle after corrections to a constant carcass weight by covariance analysis (Table 2). Pasture-finished cattle have been reported previously to produce carcasses with less fat even when the growth rates have been similar (Steen, Lavery, Kilpatrick, & Porter, 2003). Mean maturity scores were lowest for the NZAge group, and highest for the NZWt group (Table 2). USDA quality grade scores closely mirrored differences in marbling. Mean ultimate pH values were slightly higher for the US cattle for the LL muscle, but

none of the pH values for either the LL or the TB muscles exceeded 6.0.

The iron concentrations for the LL and TB muscles in the US cattle were the lowest of the three groups, but were not significantly lower than for the NZAge group ($P > 0.10$; Table 3). The NZWt group had muscle iron levels that were 18% higher than for the NZAge group and 35% higher than the US cattle. This difference is consistent with previous reports of higher iron or pigment concentrations in muscle from older cattle (Boccard et al., 1979; Jacobson & Fenton, 1956; Powell, 1991; Tuma, Henrickson, Odell, & Stephens, 1963), but for this and other differences reported here between the three groups, it is not possible to clearly distinguish between age effects and differences that may have existed between the groups in their genetic makeup and differences in the nutritional background of the two New Zealand groups that came from different farms. The fact that the levels did not differ significantly between the US cattle and the NZAge group suggest that the contrasting nutritional backgrounds for these two groups (a high-concentrate feedlot ration versus pasture) had minimal effects. Although these results strictly apply only to this specific feedlot ration, they match other comparisons of pasture versus grain finished cattle (Lanari, Brewster, Yang, & Tume, 2002). Group differences in total iron content were paralleled by differences in the percentage of that iron as haem iron (Table 3), which is consistent with other comparisons where higher levels of iron in meat have been associated with a higher proportion of the iron as haem iron (Purchas et al., 2003). The higher percentage of total haem iron for the NZWt group was reflected in a higher proportion of insoluble haem iron, but the percentage of soluble haem iron was lowest for that group, although not significantly different from the NZAge group (Table 3). Significant differences between

Table 2

Carcass and meat characteristics of feedlot-finished Angus-cross heifers from the USA (US cattle) and New Zealand pasture-finished Angus-cross heifers either of a similar age (NZAge) or a similar weight (NZWt) to the US cattle

	US cattle	NZ cattle		Group effect ^a	Carcass wt effect ^a	$R^2(\%)$, RSD ^b
		NZAge	NZWt			
Number of animals	15	8	8			
Animal age range (mo)	16–17	16–17	27–28			
Hot carcass weight (kg)	321.9c	260.1a	294.4b	***	—	61, 21.4
Adjusted fat depth (mm)	15.2b	7.75ab	9.80a	***	*	51, 3.1
Marbling ^c	428.5c	172.9a	342.3b	***	***	83, 36.2
Maturity ^d	160.7b	151.3a	191.1c	***	—	72, 10.1
US Quality grade ^e	310.6c	181.9a	227.4b	***	—	84, 25.2
Longissimus (LL) muscle pH ^f	5.54c	5.49b	5.44a	***	—	59, 0.04
Triceps brachii (TB) muscle pH ^f	5.51	5.47	5.47	+	—	17, 0.05

^a ***, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$; +, $P < 0.10$; ns, $P > 0.10$.

^b Measures of goodness of fit of the model are given by coefficients of determination [$R^2(\%)$] and residual standard deviations (RSD). Means within a row do not differ significantly ($P < 0.05$) if they have a common letter or if they have no letters.

^c Higher values indicate more marbling (e.g., USDA small = 400–500).

^d Higher values indicate an increased maturity (e.g., USDA A = 100–199).

^e Higher values indicate a higher quality grade (e.g., USDA Select = 200–299).

^f Ultimate meat pH.

Table 3

Levels of iron and the proportion of that iron in the soluble and insoluble haem and non-haem forms in the longissimus and triceps brachii muscles of cattle from three groups. Interactions between group and muscle were not significant ($P > 0.05$)

	Total iron ($\mu\text{g g}^{-1}$)	Soluble iron (%)		Insoluble iron (%)		Total haem iron (%)
		Haem	Non-haem	Haem	Non-haem	
<i>Group</i>						
US cattle ($n = 15$)	16.5a	75.7b	6.5c	9.6a	8.2a	85.3a
NZAge ($n = 8$)	18.8a	74.1ab	5.2b	11.4a	9.4b	85.5a
NZWt ($n = 8$)	22.3b	71.3a	4.5a	16.0b	8.2a	87.3b
Group effect ^a	***	**	***	***	**	***
<i>Muscle</i>						
Longissimus ($n = 31$)	17.5	75.3	5.4	12.4	6.9	87.7
Triceps brachii ($n = 31$)	20.9	72.1	5.4	12.3	10.3	84.4
Muscle effect ^a	***	**	ns	ns	***	***
$R^2(\%)$, RSD ^b	93, 1.4	69, 3.8	70, 1.1	68, 4.0	82, 1.5	79, 1.8

^a ***, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$; +, $P < 0.10$; ns, $P > 0.10$.

^b Measures of goodness of fit of the model are given by coefficients of determination [$R^2(\%)$] and residual standard deviations (RSD). Group means within a column do not differ significantly ($P < 0.05$) if they have a common letter.

the groups existed for the percentage of iron as soluble and insoluble non-haem iron, but these represented a small fraction of total iron and the differences are not considered to be of practical importance. Results in Fig. 1 show that, relative to the two NZ cattle groups combined, samples from the US cattle contained less total iron, but a higher proportion of that iron was as soluble haem iron.

The higher concentrations of iron in the TB muscle than the LL muscle (Table 3, Fig. 2) has been reported previously for beef (Schricker, Miller, & Stouffer, 1982; Purchas et al., 2003). In this case, it was associated with a higher percentage of insoluble non-haem iron rather than in the percentage of either soluble or insoluble haem iron, both of which were significantly lower for the TB muscle.

For the 10 pasture-finished animals with data for three muscles and liver (Table 4), differences between the NZAge group and the NZWt group were similar to

those in Table 3 for total iron, with higher levels in the older NZWt group, but there were no significant group differences for the percentage of iron in the different fractions. This may have been due either to the smaller number of animals or to the fact that data for the cheek muscle and liver were included. Differences between the LL and TB muscles generally paralleled those in Table 3, and were smaller than differences between those two muscles and cheek muscle. The latter contained appreciably more iron (53% more than TB and 85% more than LL) but a lower proportion of that iron in the haem form. Within the haem iron of the cheek muscle, only 61% was water-soluble, in contrast to 82% for TB and 85% for LL. The higher percentage of non-haem iron in cheek muscle was mainly due to a higher proportion of insoluble non-haem iron. It is not clear why the cheek muscle samples contained more iron in the insoluble form (47%) than the LL and TB muscles (21% and 25%, respectively), both for the haem iron and the non-haem

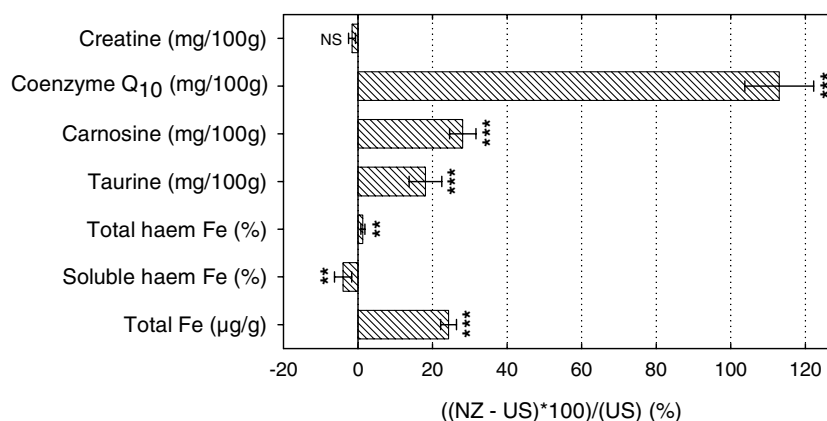


Fig. 1. Mean differences (\pm SE) between concentrations in meat from NZ cattle (NZ) and US cattle (US) expressed as a percentage of the value for US cattle. Standard errors are the model RSD divided by $\sqrt{(15)}$ (the number of US cattle) expressed as a percentage of the value for US cattle. Values used to calculate percentage differences were concentrations relative to fresh weight except total haem iron and soluble haem iron which were expressed as percentages of total iron. Significance of the difference from zero: ***, $P < 0.001$; **, $P < 0.01$; NS, $P > 0.10$.

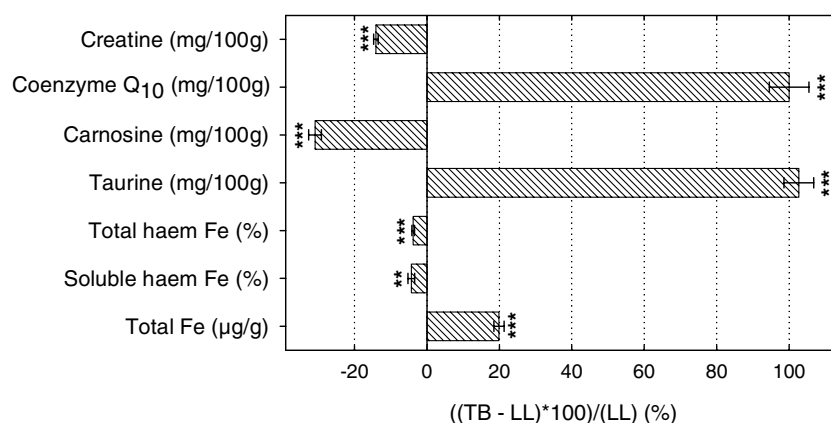


Fig. 2. Mean differences (\pm SE) between concentrations in meat from the triceps brachii muscle (TB) and the longissimus muscle (LL) expressed as a percentage of the value for LL. Standard errors are the model RSD divided by $\sqrt{(31)}$ (the total number of cattle) expressed as a percentage of the value for LL. Values used to calculate percentage differences were concentrations relative to fresh weight except total haem iron and soluble haem iron which were expressed as percentages of total iron. Significance levels are as for Fig. 1.

Table 4

Levels of iron and the proportion of that iron in the soluble and insoluble haem and non-haem forms in three muscles and the liver from 10 pasture-finished heifers

	Total iron ($\mu\text{g g}^{-1}$)	Soluble iron (%)		Insoluble iron (%)		Total haem iron (%)
		Haem	Non-haem	Haem	Non-haem	
<i>Group</i>						
NZAge ($n = 6$)	29.8	58.7	9.6	18.4	13.3	77.1
NZWt ($n = 4$)	33.5	55.5	10.1	20.3	14.1	75.8
Group effect ^a	*	ns	ns	ns	ns	ns
<i>Tissue</i>						
Longissimus muscle	17.8a	74.6c	4.9a	13.0a	7.6a	87.6c
Triceps brachii muscle	21.5b	69.8c	4.9a	15.0ab	10.3a	84.8c
Cheek muscle	32.8c	47.6b	5.5a	30.8c	16.2b	78.4b
Liver	54.5d	36.6a	24.2b	18.7b	20.5c	55.3a
Tissue effect ^a	***	***	***	***	***	***
Group \times tissue interaction ^{a,b}	*	*	ns	+	ns	ns
$R^2(\%)$, RSD ^c	96, 3.4	94, 5.1	92, 3.2	84, 4.5	78, 3.5	91, 2.2

^a ***, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$; +, $P < 0.10$; ns, $P > 0.10$.

^b The nature of the significant interactions are explained in the text.

^c Measures of goodness of fit of the model are given by coefficients of determination [$R^2(\%)$] and residual standard deviations (RSD). Tissue means within a column do not differ significantly ($P < 0.05$) if they have a common letter.

iron. It would be of interest to determine whether this difference in solubility was reflected in the bioavailability of iron from that muscle, as iron in the soluble form in the duodenum is more readily absorbed (Conrad & Umbreit, 2000).

Levels of iron in the liver were higher than for the muscles (Table 4) as has been reported elsewhere. For example, Greenfield, Kuo, Hutchison, and Wills (1987) reported iron levels of $23 \mu\text{g g}^{-1}$ for beef rib-eye steak (primarily the LL muscle), while iron levels of $58 \mu\text{g g}^{-1}$ were found for beef liver (Hutchison, Nga, Kuo, & Greenfield, 1987). Pommier, Lapierre, de Passille, and Garipey (1995) reported liver levels of iron in veal calves to be more than double those for the LL muscle. The higher iron levels for the rib-eye steak of Greenfield et al. (1987) relative to the LL values in Tables 3 and 4, may be due to some muscles other than LL being included

with the steak and the fact that the animals used in the current work were relatively young. As expected, the liver samples contained a lower proportion of iron in the haem form than the muscles, and it is likely that most of this was as haemoglobin rather than myoglobin (Martinez-Torres, Leets, Renzi, & Layrisse, 1974). Most of the liver iron was in the non-haem form with an approximately equal proportion in the soluble and insoluble fractions. The significant interaction between group and tissue for total iron ($P < 0.05$, Table 4) arose from the fact that liver iron levels were 20% higher for the NZWt group, whereas the levels in the muscles ranged from 6% to 8% greater for that group, probably reflecting the more labile nature of liver iron supplies. The interaction for the percentage of soluble haem iron was due to the value being lower for NZWt for all tissues except cheek muscle which had a slightly higher value.

The four tissues shown in Table 4, however, were ranked the same for total iron and for percentage soluble haem iron for both groups of cattle.

The nature of the iron compounds in the four fractions is not known, but it is expected that the main component of the soluble haem fraction was myoglobin.

3.2. Levels of other compounds

Of the five compounds shown in Table 5, all except creatine differed significantly in concentration between the three groups for the LL and TB muscles, with lower values in each case for the US cattle than the NZ cattle. Differences between the NZAge and NZWt groups were not significant ($P > 0.05$). When expressed as a percentage of the values for the US cattle (Fig. 1), the NZ cattle samples showed the biggest difference in coenzyme Q₁₀ (113% higher than the US cattle), followed by carnosine (28% higher), taurine (18% higher), and creatinine (11% higher). The higher level for creatinine without any difference in creatine is difficult to explain as the former is likely to be present in muscle as a breakdown product of the latter (Wyss & Kaddurah-Daouk, 2000).

It is not possible to be certain about why the levels of coenzyme Q₁₀, carnosine and taurine were lower in muscles from the US cattle because there were several differences in their background as noted earlier in this paper. In the study of Watanabe, Ueda, and Higuchi (2004), taurine levels in the longissimus muscle of cattle were reported to increase with animal age, while carnosine concentrations decreased. In the same study, longissimus muscle from Japanese Black cattle contained higher levels of taurine and lower concentrations of carnosine, which the authors suggested may have been due to more oxidative muscle fibres in the muscle from these cattle relative to the Shorthorn and Holstein cattle they were

compared with. Thus, there may have been genetic differences between the US and NZ cattle of the current study that accounted for some of the differences reported. It is not known whether the relatively high levels of potato products in the feedlot diet (Table 1) would have had an effect on these compounds.

The size of the differences in Table 5 and Fig. 1, although of high statistical significance, need to be considered in relation to the sorts of levels of these compounds available as supplements. In the case of coenzyme Q₁₀, for example, the mean levels of less than 3 mg in a 100 g serving of meat is well below the levels of over 100 mg d⁻¹ that have been used as supplements in human trials, albeit for relatively short periods (Hargreaves, 2003; Malm, Svensson, Ekblom, & Sjodin, 1997; Overvad et al., 1999).

The significant muscle effects shown in Table 5 and Fig. 2 are consistent with those reported by Purchas et al. (2004) and are generally those to be expected for muscles that differ in the proportions of muscle fibre types. Thus, TB, which has a higher proportion of the red type I fibres (Karlstrom, Essen-Gustavsson, & Lindholm, 1994; Talmant, Monin, Briand, Dadet, & Briand, 1986), contained higher concentrations of taurine and coenzyme Q₁₀, but lower concentrations of carnosine, creatine and creatinine. The buffering effects of carnosine and the emergency supplies of high-energy phosphate bonds in creatine phosphate are more likely to be required in fibres with less oxidative capabilities, while coenzyme Q₁₀ is present mainly in mitochondria, which are more abundant in red-type fibres. The reasons for higher levels of taurine in the TB muscle are not clear although they may be on account of its antioxidant properties. The concentrations of taurine reported here are somewhat higher than those reported by Spitze, Wong, Rogers, and Fascetti (2003) from beef of unspecified muscles and background.

Table 5
Levels of taurine, carnosine, coenzyme Q₁₀, creatine and creatinine in the longissimus and triceps brachii muscles of cattle

	Taurine (mg 100 g ⁻¹)	Carnosine (mg 100 g ⁻¹)	Coenzyme Q ₁₀ (mg 100 g ⁻¹)	Creatine (mg 100 g ⁻¹)	Creatinine (mg 100 g ⁻¹)
<i>Group</i>					
US cattle	68.9a	308.0a	1.23a	360	5.5a
NZAge	82.8b	403.8b	2.51b	349	6.0b
NZWt	79.9b	385.6b	2.73b	360	6.2b
Group effect ^a	**	***	***	ns	**
<i>Muscle</i>					
Longissimus	51.0	432.6	1.44	383	6.2
Triceps brachii	103.4	299.1	2.88	329	5.6
Muscle effect ^a	***	***	***	***	***
Group × muscle interaction ^{a,b}	**	ns	***	***	*
R ² (%), RSD ^c	92, 11.7	90, 42.4	93, 0.44	94, 13	78, 0.6

^a ***, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$; +, $P < 0.10$; ns, $P > 0.10$.

^b The nature of the significant interactions are explained in the text.

^c Measures of goodness of fit of the model are given by coefficients of determination [R^2 (%)] and residual standard deviations (RSD). Group means within a column do not differ significantly ($P < 0.05$) if they have a common letter or have no letters.

Significant group-by muscle interactions occurred for some compounds (Table 5), but generally these did not affect the validity of the generalizations made above. In the case of coenzyme Q₁₀, the differences between the US cattle and NZ cattle were similar for both muscles, and the TB value was higher than the LL value for each group, but the muscle difference was smaller for the US cattle than for the NZ cattle. For taurine, the group effect was more apparent for the TB muscle than for the LL muscle where it was not significant ($P > 0.05$). For creatine, the muscle effect was consistent across the three groups, but a group effect showing the NZAge group to have lower values than the other two groups, was apparent for the LL muscle only.

With both coenzyme Q₁₀ and carnosine having antioxidant properties, it may be that they play a role along with higher vitamin E levels (Kerry, Buckley, & Morrissey, 2000) in giving beef from pasture-finished cattle the improved oxidative stability that has been reported in some studies (Lanari et al., 2002; Realini, Duckett, & Windham, 2004).

Table 6 shows results for the sub-sample of 10 pasture-finished NZ cattle for which information on the composition of samples from the cheek muscle and liver were available. The two groups of NZ cattle did not differ significantly for any of the five compounds shown in Table 6, and the differences between the LL and TB muscles generally paralleled those shown for the larger group of cattle (Table 5), with the LL containing less taurine and coenzyme Q₁₀, but more carnosine and creatine. Cheek muscle, which was mainly the masseter muscle, was chosen because it contains a high proportion of red type I fibres (Karlstrom et al., 1994; Talmant et al., 1986), so the results in Table 6 showing very high levels of taurine and coenzyme Q₁₀, along with lower levels of carnosine, creatine and creatinine were expected,

although the sizes of the differences between TB and cheek were greater than between TB and LL. In a previous report comparing beef cheek muscle and the semitendinosus muscle (Purchas et al., 2004), differences of a similar magnitude were found for a small number of samples, but in that case it was not known if the pairs of samples came from the same animals, and little was known about the background of the animals. Liver concentrations for taurine, carnosine, and coenzyme Q₁₀ (Table 6) were at the low end of the range for the three muscles, while liver creatine levels were much lower than for the muscles. Liver concentrations of taurine reported by Spitze et al. (2003) were variable with some being higher and some lower than the mean reported here. For coenzyme Q₁₀, these results contrast with those of Ibrahim, Bhagavan, Chopra, and Chow (2000) for rats where levels of coenzyme Q₁₀ and Q₉ were many times higher in liver than in muscle, although the specific muscles analysed were not specified. It was also noted in that paper that levels in liver responded to a much greater extent than those in muscle to dietary supplements of coenzyme Q₁₀. Creatinine levels in liver were lower than those in LL and TB, but higher than levels in the cheek muscle.

The significant group \times tissue interaction for creatine (Table 6) reflects the fact that levels were significantly higher for the NZWt group for the LL muscle ($P < 0.01$) but significantly lower for liver ($P < 0.05$). For both groups, however, the ranking of the four tissues was the same.

4. Conclusions

In this comparison of beef from similar cattle from different production systems in different countries the

Table 6
Levels of taurine, carnosine, coenzyme Q₁₀, creatine and creatinine in three muscles and liver of 10 pasture-finished Angus-cross heifers

	Taurine (mg 100 g ⁻¹)	Carnosine (mg 100 g ⁻¹)	Coenzyme Q ₁₀ (mg 100 g ⁻¹)	Creatine (mg 100 g ⁻¹)	Creatinine (mg 100 g ⁻¹)
<i>Group</i>					
NZAge ($n = 6$)	201.0	239.1	3.34	260.3	4.62
NZWt ($n = 4$)	203.5	229.3	3.24	256.1	5.08
Group effect ^a	ns	ns	ns	ns	ns
<i>Tissue</i>					
Longissimus	48.4a	427.6c	1.80a	381.6d	6.15c
Triceps brachii	108.1b	327.9b	3.54b	336.6c	6.08c
Cheek muscle	610.9c	79.0a	6.22c	266.4b	2.67a
Liver	41.7a	102.3a	1.60a	48.3a	4.48b
Tissue effect ^a	***	***	***	***	***
Group \times tissue interaction ^{a,b}	ns	ns	ns	**	ns
R ² (%), RSD ^c	99, 35.1	98, 28.5	95, 0.58	99, 16.3	90, 0.63

^a ***, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$; ns, $P > 0.10$.

^b The nature of the significant interactions are explained in the text.

^c Measures of goodness of fit of the model are given by coefficients of determination [R^2 (%)] and residual standard deviations (RSD). Tissue means within a column do not differ significantly ($P < 0.05$) if they have a common letter.

results need to be interpreted with caution, but they suggest that beef from US feedlot-finished cattle contained less iron than that from pasture-finished cattle in NZ, possibly due in part to an age effect. In addition, the feedlot-finished beef contained lower levels of taurine, carnosine, and coenzyme Q₁₀, but not creatine.

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